

Summary of Session A6, Alternative Theories of Gravity

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I. INTRODUCTION

The session on *Alternative Theories of Gravity* had perhaps the greatest number of contributed papers out of all the parallel sessions at GR15. In all there were 84 contributions which spanned an enormous breadth of alternative ideas concerning classical and quantum gravity. For the most part, these ideas naturally grouped themselves into five categories: (a) Black Holes, (b) Tests of Alternative Gravitational Theories, (c) Lower-Dimensional Gravity (d) Membranes and Solitons and (e) Methods and Geometrical Structures. There were 20 oral presentations made, with a total of four hours being allotted to the sessions. The sessions on black holes, tests and lower dimensions were particularly well attended. Below follows a brief summary of each of the five sections. The sequence of oral presentations was determined alphabetically (last name of first author) for each section.

II. BLACK HOLES

There were three oral presentations given here. A. Bonanno presented some recent results he obtained for mass inflation in higher derivative theories of gravity [1]. The goal of this work is to gain some insight as to how the classical description of the mass inflation singularity is altered by quantum effects. Such effects are generally modelled by modifying the Einstein-Hilbert action so that it includes terms non-linear in the curvature (*i.e.* the higher-derivative terms); these might be dynamically generated during gravitational collapse. For the Reissner-Nordstrom-Vaidya black holes, both the location and surface gravity of the inner horizon are modified. The impact of this on the mass inflation phenomenon can only be determined by detailed calculation, although it appears that the basic instability properties of the Cauchy horizon will not change.

The interior structure of non-Abelian black holes was the subject of G. Lavrelashvili's talk [2]. Unlike their Abelian counterparts, no inner (Cauchy) horizon forms inside them. Instead, a different sort of mass inflation occurs in which an enormous growth of the mass function takes place just before a Cauchy horizon can form. There are repeated cycles of this phenomenon in the absence of a Higgs field, whereas no such cycles occur if a Higgs field is present.

Finally, J. Koga (in collaboration with K. Maeda), considered the behaviour of black hole thermodynamics in gravitational theories in which the action is a functional of the metric, the Ricci tensor, a scalar field and its derivative. These theories can be converted to general relativity via a "Legendre transformation". For two black hole solutions related by such a transformation, all thermodynamic variables are found to be the same, but the gravitational mass differs.

III. TESTS OF ALTERNATIVE THEORIES

This part of the session had two talks. J. Novak spoke about the possible empirical interest of tensor-scalar gravity: even if it is tightly constrained by solar-system experiments to behave almost like general relativity in the weak-field limit, it could differ from it significantly in the strong-field regime. Compact objects (*e.g.* neutron stars) would radiate scalar gravitational waves as they collapsed, and these could be interferometrically detected with technology currently under construction. Results from numerical simulations of the collapse of a stellar core into a neutron star were presented. This work will soon be published [3].

The other talk by A. Edery (collaborating with M. B. Paranjape), considered the empirical viability of Weyl gravity in the context of light deflection of light [4]. An extra deflection term beyond the usual one in general relativity is obtained, and this term is significant at large (galactic or greater) distance scales where dark matter effects are observed. However the sign of the extra correction term is opposite to that needed to fit galactic rotation curves. This leads to two possibilities: either Weyl gravity cannot solve the dark matter problem or fitting galactic rotation curves in a conformal theory(a massless theory) is in the first place not a reliable procedure until one introduces a symmetry breaking mechanism.

IV. LOWER-DIMENSIONAL GRAVITY

This was quite a popular section of the session, with a considerable number of oral and poster presentations. M. Cataldo [5] (collaborating with P. Salgado) described work which shows how to obtain a solution to the $(2+1)$ -dimensional Einstein-Maxwell equations for a charged spinning black hole, correcting previous work by Kamata and Koikawa on this problem. Furthermore, a electromagnetic duality mapping amongst different spinning solutions was shown to exist.

R. Tavakol (working with J.E. Lidsey and C. Romero) presented work which described a constructive method for finding higher-dimensional vacuum solutions from those in lower-dimensions by making use of an embedding theorem due to Campbell. Examples include finding local embeddings of general relativistic solutions in Ricci-flat 5-dimensional spaces as well as showing how to relate $(2+1)$ -dimensional gravity to vacuum $(3+1)$ -dimensional general relativity. Tavakol also claimed that this approach could yield new solutions. This work has recently been published [6].

T. Ohta (in collaboration with R.B. Mann) described some preliminary results of a consideration of the 2-body problem in $(2+1)$ -dimensional general relativity. An exact solution for the reduced Hamiltonian as a function of the relative position and momentum can be obtained in the case of two massless bodies. This solution furthermore has a very interesting resemblance to an exact solution to the 2-body problem they recently obtained in $(1+1)$ dimensions [7]. Further implications of these results are being worked out.

B. Paul (working with S. Mukherjee and A. Beesham), interested in investigating dissipative thermodynamic effects in cosmological models, described results of an investigation of such effects in $(1+1)$ -dimensional gravity, where mathematical simplicity affords one considerable computational progress. $R = T$ theory was chosen because a considerable number of its properties and solutions closely resemble those of general relativity. A number of results were obtained, including a demonstration of the unphysical aspects of Eckart theory, solutions with oscillating Hubble parameter, and double-inflation solutions.

J. Soda gave a talk showing how 2-dimensional gravity (including constant curvature theories, the CGHS model, and spherically symmetric gravity) could be pressed into service to shed light on critical phenomena in gravitational collapse. Self-similar solutions are generally believed to provide a good approximation to the non-linear dynamics present in gravitational collapse. However Soda finds that not all self-similar models elicit critical phenomena.

Finally, Vendrell gave a talk described a new black-hole solution of $(1+1)$ -dimensional " $R = T$ " theory which is the endpoint of the collapse of an infinitesimally thin shell of radiation. The interior singularity has the topology of a corner, and the black hole may be considered as a two-dimensional analog of the Schwarzschild black hole. Vendrell discussed some of its semi-classical and quantum properties. Some of this work has been published [9].

V. MEMBRANES AND SOLITONS

This part of the alternative theories session dealt with new ideas for incorporating extended objects into gravitational theory. D. Gal'tsov (in collaboration with Chen) described work in which sigma-model representations were derived for P -branes corresponding differing decompositions of the full metric. Transformations which generate solutions preserving asymptotic flatness of the metric were discussed, and in the case where the solutions depended on two transverse coordinates, associated Geroch-type symmetries are present.

P -branes were employed in a somewhat different way in talk given by M. Grebniuk (with V.D. Ivashchuk V.D. and V.N. Melnikov). He began with a multidimensional cosmological model that described the behaviour of $n+1$ Einstein spaces for which the action contained a number of dilatonic scalar fields φ^a and antisymmetric forms A^I . The P -branes enter when the φ^a forms are chosen to be proportional to the volume elements of the " p -brane" submanifolds. The general motivation behind this work appears to be in understanding the general ways in which gravity (in a cosmological setting) might be ultimately described in terms of some kind of membrane physics. A Toda-like Lagrangian representation arises, and it is possible to obtain exact solutions to the field equations in certain circumstances.

M. Pavsic gave a talk in which he proposed that spacetime itself be considered as an n -dimensional membrane embedded in a (presumably extra-physical) N dimensional manifold. As no constraints are imposed on the membrane, both its normal and tangential motions are physically relevant, and the theory can be straightforwardly quantized. The distinction between the evolution parameter of the membrane's wavepacket is distinct from the timelike coordinate of the membrane, thereby offering an approach for resolving the "problem of time" in quantum gravity.

The last talk of this section was by M. Sethi (working with D. Lohiya). In a Brans-Dicke cosmology where the scale factor evolves linearly with time, non-topological soliton solutions can arise in which spacetime breaks up into domains with differing values of the effective gravitational coupling constant. A domain consisting of a region having the canonical value of the gravitational constant surrounded by one in which this constant vanishes is called a gravity

ball (or (g)-ball). In this toy model, gravitating matter is trapped inside gravity(g)-balls as large as (say) the halo of typical galaxies. The authors claim that the resulting cosmology has no horizon, flatness or cosmological constant problems and that it is consistent with the three "classical tests" of cosmology: Number Count–Redshift, Luminosity distance–Redshift and the Angular Diameter–Redshift. Some results of this work are available in preprint form [11].

VI. GEOMETRICAL STRUCTURES

This section of the session was devoted to a consideration of ideas which question the basic geometric notions which undergird general relativity and which seek alternative means of understanding them. Approximately 30 papers contributed to the session were in this category, the largest out of all the sections. There were five oral presentations given.

L. Querella (working with S. Cotsakis and J. Miritzis) described the results of an investigation [12] of a metric-affine approach to higher order theories of gravity in which the Lagrangian is an arbitrary function of the curvature invariants. A conformal equivalence theorem between these theories and general relativity plus a scalar field was shown to hold in the extended framework of Weyl geometry with the same forms of field and self-interacting potential. However a new 'source term' appears which makes an additional contribution to the stress-energy. This approach may lead consistently to a new method of reduction of order of the associated field equations.

M. Mars (collaborating with R.M. Zalaletdinov) gave a talk in which he described a new approach for covariant space-time averaging of tensorial quantities on differentiable metric manifolds with a volume n -form. A new result was presented demonstrating that the averaging bilocal operator is idempotent iff it is factorized into a bilocal product of a matrix-valued function on the manifold, taken at a point, by its inverse at another point. Several other new results concerning the algebraic structure of the averaging operator were also mentioned.

E. Poberii's contribution presented us with the suggestion that general relativity be considered as the low-energy limit of a theory in which metric compatibility is not required, torsion is permitted, and local conformal invariance holds. Such a theory is postulated to be relevant in the very early universe. The dynamical non-metricity present in the theory can induce a type of chaotic inflation. During inflation the non-metricity tends to zero, so that our space-time currently appears to be Riemannian with a high degree of accuracy.

Non-metricity also played an important role in U. Schell's talk. He claimed that non-metricity could provide a mathematical criterion referring to non-spacelike geodesics for distinguishing between Riemannian and Weylian geometries. This in turn could be translated into operationally testable criteria based on distance measurements with light signals, without any recourse to a second clock effect in Weyl space or to atomic clocks.

The final talk of the session was given by P. Smrz, who described an approach toward describing physical fields in geometrical terms that he has been exploring for a number of years [14]. In this approach the classical properties of space-time are derived from the geometry of a four-dimensional complex manifold with a linear connection. The measurement process forces the properties of space-time to depend on the choice of the reference cross section. The present talk described how one might hope to provide a geometric explanation for fermions.

VII. CLOSING REMARKS

The large number of abstracts submitted to this session is indicative of the robust level of interest members of the theoretical physics and mathematics communities express in considering alternatives to general relativity. Although several of these alternatives are very speculative, an increasing number of them are plausible variants of some of the basic ideas that underlie our understanding of gravitational theory. Their chief (and often under-appreciated) function is that they continually remind us that there are fresh perspectives on old (and sometimes not-so-old) problems.

- [1] A. Bonanno "The Cauchy Horizon in Higher-derivative Gravity Theories", gr-qc/9801077.
- [2] P. Breitenlohner, G. Lavrelashvili, D. Maison "Mass inflation inside non-Abelian black holes", gr-qc/9711024.
- [3] J. Novak, "Spherical neutron star collapse toward a black hole in tensor-scalar theory of gravity", gr-qc/9707041 (to appear in *Phys. Rev. D*).
- [4] A. Edery and M.B. Paranjape, "Classical tests for Weyl gravity: deflection of light and radar echo delay" astro-ph/9708233.

- [5] M. Cataldo and P. Salgado, "The Electrically Charged Extreme BTZ Black Hole with Self (Anti-self) Dual Maxwell Field", gr-qc/9611004.
- [6] J. Lidsey, C. Romero, R. Tavakol, and S. Rippl, Class. Quantum Grav., **14**, (1997) 865.
- [7] T. Ohta and R.B. Mann, Class. Quant. Grav. **14** (1997) 1259.
- [8] J. Soda and K. Hirata, Phys. Lett. **B387** (1996) 271.
- [9] F. Vendrell, "A black hole in two-dimensional space-time", hep-th/9705135; Helv. Phys. Acta **70** (1997) 598.
- [10] M. Pavsic, Nuovo Cim. **110A** (1997) 369; Nucl. Phys. Proc. Suppl. **57** (1997) 265; Found Phys. **26** (1996) 159; Found. Phys. **25** (1995) 819.
- [11] M. Sethi *et. al.*, "A Program for a Problem Free Cosmology Within a Framework of a Rich Class of Scalar-tensor Theories"; IUCIAA-61-97, (Dec 1997).
- [12] S. Cotsakis, J. Miritzis and L. Querella, "Variational and Conformal Structure of Nonlinear Metric-connection Gravitational Lagrangians", gr-qc/9712025.
- [13] U. Schelb, Int. Journ. Theor. Phys. **35** (1996) 1767; **36** (1997) 1341.
- [14] P.K.Smrz, Aust. J. Phys. **50** (1997) 793; Aust. J. Phys. **48** (1995) 1045; J. Math. Phys. **28** (1987) 2824.